# The Need for a Puget Sound Mussel Watch Monitoring Program

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## Abstract
Several environmental agencies in Puget Sound have long-term monitoring programs designed to quantify the status and trends in water and sediment quality. We propose integrating existing programs with a Puget Sound Mussel Watch program to optimize the utility, comparability, and sharability of complementary data while minimizing costs associated with data collection. "Mussel Watch" is a monitoring approach that uses tissue chemistry in resident or transplanted bivalves to evaluate the status and trends in environmental quality. Our approach would include effects monitoring by measuring other endpoints such as biomarkers and growth. A Puget Sound Mussel Watch Program would integrate tissue chemistry data to link the major environmental compartments (water, sediment, tissues) and a method to focus existing programs on more common goals. It would also include a freshwater Mussel Watch element. This is important not only because of the relationship between the Puget Sound watershed and ecological health of the Puget Sound Basin, but because of declining populations of many threatened and endangered freshwater bivalve species that have not been adequately monitored. Data collection costs by each participating agency would be minimized by cost and services sharing. Additional benefits would include gathering baseline data for comparison with those from spontaneous events of concern such as oil spills, reduced uncertainty in risk assessments, utilization of tissue residue effects databases, human health evaluations, and the addition of previously underutilized monitoring species such as bivalves which are well-suited to evaluating bioaccumulative chemicals of concern. The purpose of this paper is to present the rationale and methods for establishing a Puget Sound Mussel Watch Monitoring Program, and to make specific recommendations for implementation.

## Background
Currently the National Oceanic and Atmospheric Administration (NOAA) has 14 long-term Mussel Watch stations in Puget Sound that have been used as part of the National Status and Trends monitoring program (Figure 1). However, the frequency of monitoring has decreased in recent years and it has been suggested that this national program be reduced even further or perhaps terminated. This would place an even greater burden on the state at a time when state agencies are asking for increased environmental monitoring. The Washington State Department of Natural Resources (Natural Resources) Aquatic Lands Division has used caged bivalves as part of a Mussel Watch approach to assess potential exposure of herring stocks to polyaromatic hydrocarbons (PAHs) along the Cherry Point Reach in 1998, 1999, and 2000. Caged mussel monitoring was expanded in 2000 to include Fidalgo Bay, Port Gamble, and Brownsville (Figure 1). DNR may expand Mussel Watch monitoring to include indigenous mussel populations at selected sites. This will enhance the understanding of mechanisms that control the exposure of herring stocks and other species to PAHs. This additional information will facilitate science-based decisions by DNR associated with their administration of leases for aquatic lands. The Wastewater Treatment Division of DNR has used caged and indigenous mussels to monitor combined-sewer overflows (CSOs) and is planning on attaching caged mussels to oceanographic moorings to collect data that will be used as part of the ecological risk assessment to select a site for the new north end treatment plant. Several other agencies, including the Washington State Department of Health (Health), and the Washington State Department of Ecology (Ecology) monitor natural mussel populations for chemicals, fecal coliform bacteria and biotoxins. A more coordinated effort would increase the relative value of the independent monitoring with a sharing of costs, technical expertise, and services. The United States Geological Survey (USGS) has comparable monitoring programs in freshwater and has monitored tissue chemistry in fish and bivalves throughout the US (Figure 2). Ecology also has a freshwater monitoring program in the Puget Sound watershed. It would be useful from a watershed approach to integrate these freshwater and marine monitoring programs in a more holistic approach. The purpose of this proposal is to outline the rationale and approach for establishing an "umbrella" Puget Sound Mussel Watch Monitoring Program.

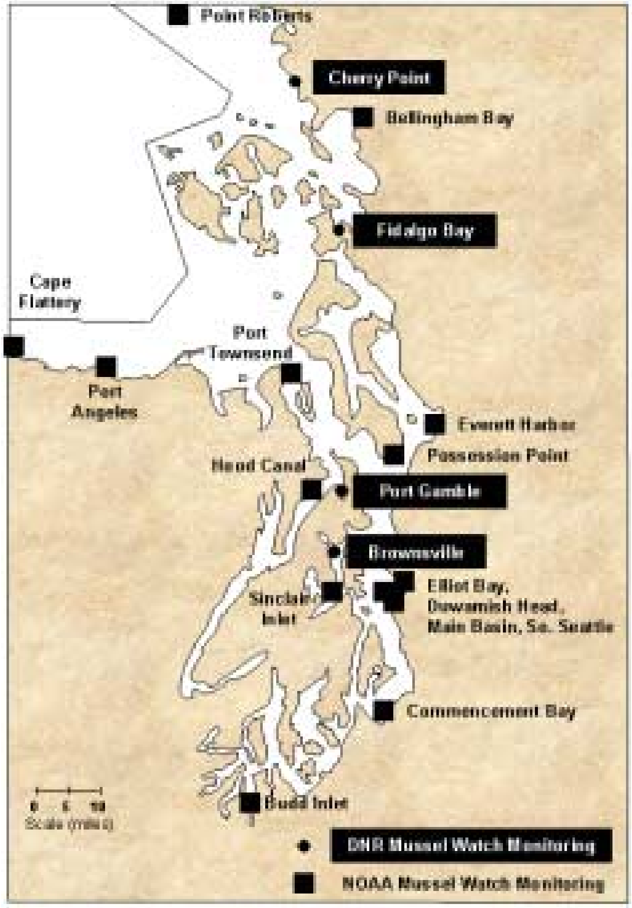


**Figure 1.** NOAA and DNR Mussel Watch monitoring locations.

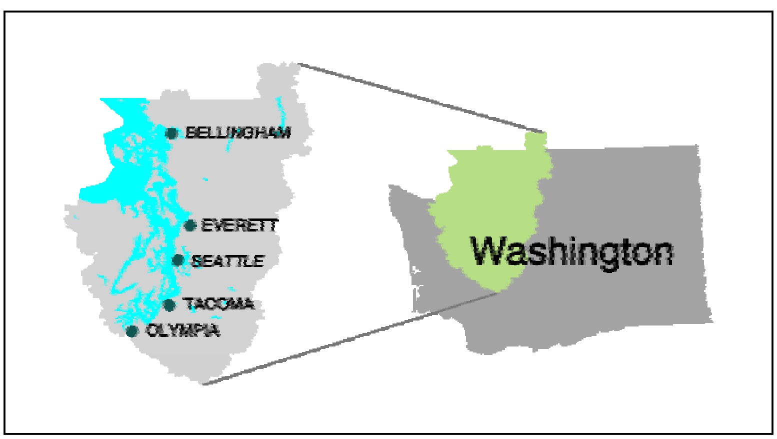


**Figure 2.** Ecology and USGS freshwater monitoring locations in the Puget Sound watershed.

# Rationale

> *"The ultimate goal is the development of a single bioassay methodology, where the kinetics of bioconcentration to a given body or tissue level are linked with an understanding of the toxicological significance of that tissue residue level. Thus the nature and time course of external exposures can be linked with related processes in the body of exposed organisms" (McCarty, 1991, ASTM STP 1124:183-192).*

Although McCarty originally made these suggestions regarding water exposures and bioconcentration (water only exposures), they also apply to field monitoring of chemicals in tissues of sentinel organisms or bioaccumulation from multiple pathways of exposure. Current approaches need to be revised because there is a need to reduce uncertainties in understanding and characterizing relevant natural processes and anthropogenic influences in PSAMP monitoring. This problem is exacerbated by the use of independent monitoring for toxicity and bioaccumulation and a heavy reliance on methods developed in the Pacific Northwest. The utility of relationships between tissue chemistry and response to predict effects in the real world is the ultimate goal of combined exposure and effects testing. Synoptic measurements of exposure and effects in the same organism would reduce the uncertainty in management decisions by Puget Sound regulatory agencies because of a more direct relationship between the external environment, tissue chemistry, and effects. Separating bioaccumulation and toxicity monitoring reduces data integration, limits understanding the processes affecting bioaccumulation and associated biological effects, and obscures the potential utility of combined exposure and effects monitoring as a predictive tool for real-world applications.

# Approach

- Integrate and focus existing programs with more cost and services sharing.
- Facilitate consistency with the risk assessment methodology of characterizing exposure and effects.
- Provide a better framework for forensic monitoring and mapping.
- Satisfy additional monitoring requirements outlined in *2000 Puget Sound Update.*
- Emphasize using more efficient tools in the environmental monitoring toolbox.
- Add previously under-utilized, yet critical, monitoring species.

"Mussel Watch" is a monitoring approach that typically includes measuring tissue chemistry in resident or transplanted bivalves at regular intervals to establish the status and trends in environmental quality. The approach suggested here would also include measuring other endpoints such as biomarkers and growth to add an effects component to the monitoring. This proposal will make specific recommendations regarding the use of: (1) Mussel Watch monitoring of bioaccumulation and biomarkers to establish links between Mussel Watch monitoring, monitoring by Puget Sound Ambient Monitoring Program (PSAMP) and other agencies (Figure 3); (2) Mussels in an exposure-dose-response approach to ambient monitoring (Figure 4); (3) An integrated exposure-dose-response triad in PSAMP monitoring (Figure 5); (4) Tissue chemistry and biochemistry (biomarkers) to establish links within field monitoring elements (bioassays, benthos and fish) and laboratory monitoring elements (bioassays and communities) (Figure 6); (5) Mussel Watch monitoring of tissue chemistry, biochemistry and microbes to establish links to toxic contamination, human health, biological resources, pathogens and nutrients, and physical environment within the PSAMP model (Figure 7); and (6) Predicting effects with body burdens (Figure 8).

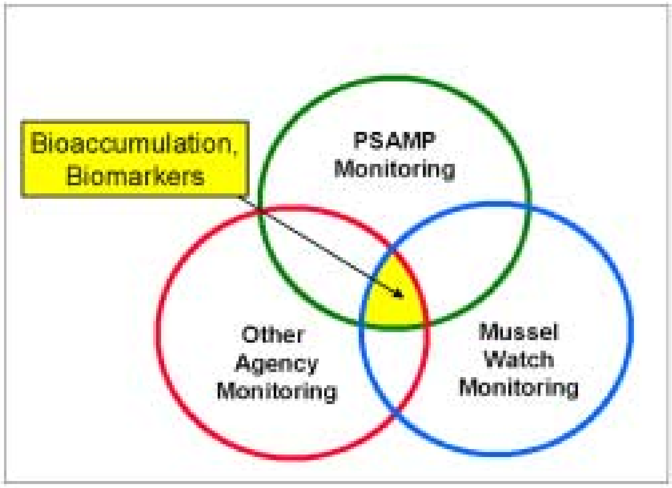


**Figure 3.** Using bioaccumulation and biomarkers as links in a Puget Sound Mussel Watch program.

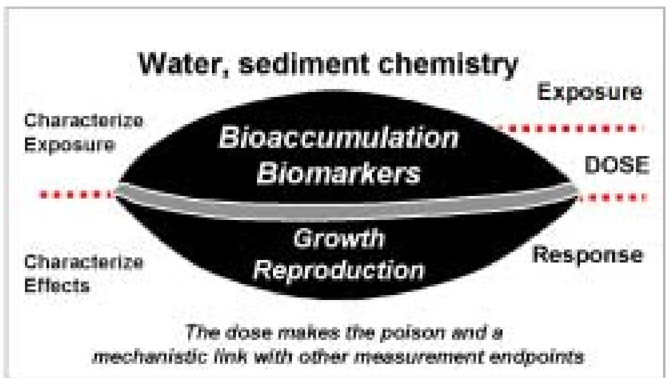


**Figure 4.** The exposure-dose-response triad using mussels.

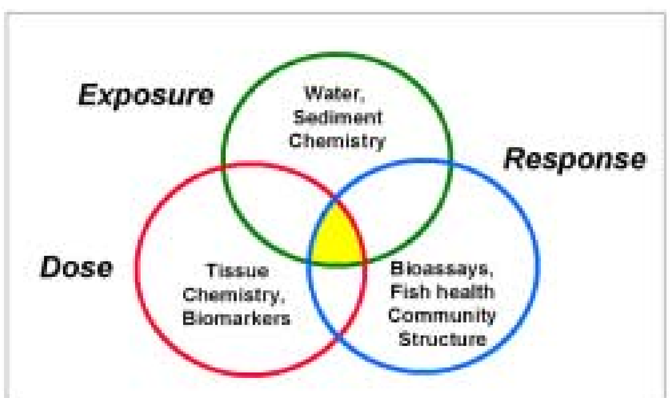


**Figure 5.** The integrated exposure-dose-response triad in PSAMP monitoring

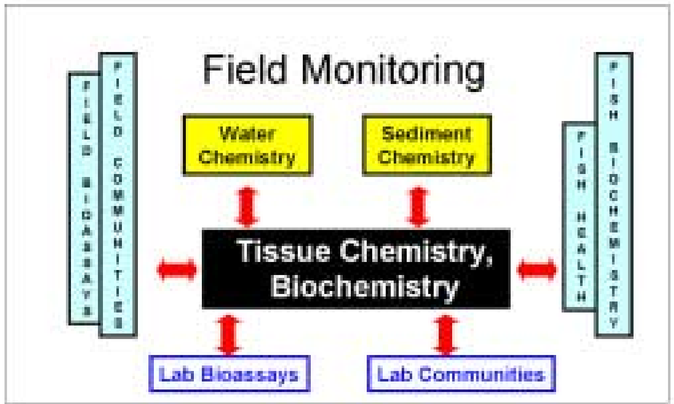


**Figure 6.** Using tissue chemistry and biochemistry to establish links between lab and field.

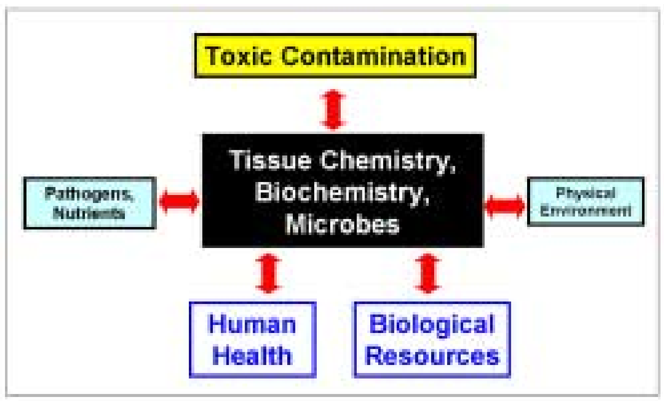


**Figure 7.** Using tissue chemistry, biochemistry and microbes in Mussel Watch to establish PSAMP links.

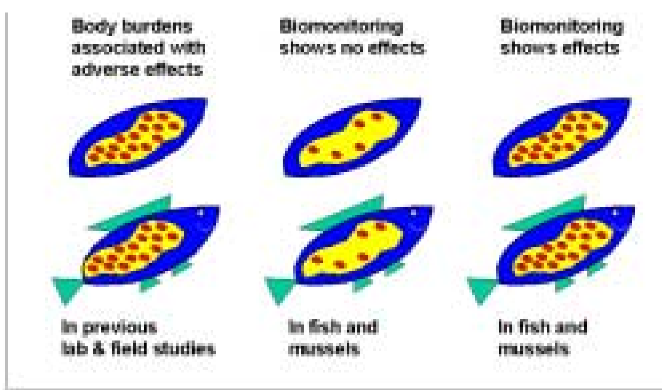


**Figure 8.** Predicting effects with body burdens by comparing those associated with adverse effects in previous studies with those from Mussel Watch monitoring.

**An Integrated Monitoring Strategy**
Due to shrinking budgets, an increasing number of potential environmental issues, an increasing complexity in the problems to be addressed, and a desire for more sensitive and integrated monitoring endpoints, there is a need to **better integrate existing monitoring programs**. As shown below, there are two areas of integration that would greatly benefit regional monitoring in Puget Sound: agency integration and monitoring integration. Mussel Watch monitoring that includes indicators of exposure such as bioaccumulation and biomarkers and indicators of effects such as growth and reproduction can be used to link results from various monitoring programs. Currently, each agency provides marine monitoring data to the PSAMP where it is collated and made available for end-users. One missing link, however, is freshwater monitoring which is not included in PSAMP and is not collated by any agency. USGS has a national monitoring program in freshwater that includes both indigenous and transplanted bivalves but not in Washington State. Given the recent interest in landscape ecology and the contribution of watersheds to the ecological health of the Puget Sound Basin, integrating **freshwater and marine monitoring** is timely. Decreasing populations of many threatened and endangered freshwater bivalve species, increases the urgency of this freshwater monitoring. A sound-wide Mussel Watch Program could provide a **link for existing monitoring programs** and more interagency cooperation. Furthermore, since NOAA has decreased the frequency of mussel watch monitoring in recent years, a Puget Sound mussel watch is needed to maintain the same level of monitoring.

**Agency Links**
- *Washington State Department of Ecology* (sediment, marine water, and freshwater)
- *Washington State Department of Fish & Wildlife (DFW)* (fish contaminants, fish abundance, and marine birds & mammals)
- *Washington State Department of Health* (shellfish)
- *Washington State Department of Natural Resources - Aquatic Lands* (nearshore habitat)
- *Washington State Department of Natural Resources - Wastewater Treatment Division* (marine water, sediment, & shellfish)
- *U.S. Environmental Protection Agency*
- *U.S. Fish & Wildlife Service* (bird contaminants)
- *U.S. Geological Survey* (freshwater monitoring, fish & shellfish monitoring)
- *National Marine Fisheries Service(NMFS)* (fish health, sediment, endangered species)
- *NOAA Mussel Watch* (mussels & oysters)

**Monitoring Links**
- *Lab & field bioassays, benthos structure*
- *Water, sediment & tissue chemistry*
- *Experiments & observations*
- *Ecological & human health*
- *Fish & bivalve biomarkers*
- *Marine & freshwater*
- *Lab & field*

Regardless of the intended use of the data by individual agencies, participating agencies would provide their monitoring data to the PSAMP where it would be collated and made available for their end-users as part of a cooperative agreement. Recently, sound-wide sediment bioassays have been included as part of a cooperative agreement between the Ecology and NOAA. This is an example of recognition by PSAMP that there are other tools in the environmental monitoring toolbox that can be applied to Puget Sound to help quantify the extent of contamination and associated adverse biological effects.

The Pacific Northwest has been a focal point for the development of many innovative monitoring and assessment protocols such as the sediment quality triad, apparent effects threshold (AET), sediment quality guidelines, amphipod bioassay, bivalve bioaccumulation bioassay, polychaete growth test, and bioaccumulation triggers for additional sediment testing. However, the utilization of marine and freshwater Mussel Watch monitoring has lagged behind other states. Given this level of innovation and environmental awareness within the state, it is surprising that the State of Washington does not have a Mussel Watch program. It may have been the success of these other approaches that have masked the utility of monitoring indigenous and caged bivalves.

Various agencies, local colleges and universities, and private consulting firms have conducted a number of independent Mussel Watch studies in Puget Sound. These studies include the use of caged bivalves in more directed studies such as at the Harbor Island Superfund Site, Sinclair Inlet, Cherry Point, and a number of other sites within Puget Sound. However, many of these efforts have been fragmented, lacking the regional scale that is found in California programs. The State of California has a statewide Mussel Watch monitoring program that includes both indigenous populations and caged mussels. Established in 1977, this is the longest running Mussel Watch program in the US. Several years ago the San Francisco Estuary Institute began a more focused Regional Monitoring Program for San Francisco Bay. For Puget Sound, we propose a Mussel Watch monitoring model that includes elements of the successful state program in California and the national program administered by NOAA.

A Puget Sound Mussel Monitoring Watch Program could provide the **link**, or common thread, that would tie together each of the individual Sound-wide monitoring programs by measuring exposure elements such as bioaccumulation and biomarkers (Figure 3). By organizing and focusing their efforts under an umbrella Mussel Watch program, others could use these data to reduce uncertainty in their measurements and conclusions. Consistency would be maintained across studies by establishing guidelines and standardized protocols for these types of studies. The end result would be more useful, sharable, and comparable data. PSAMP is the most likely organization to accommodate and implement such a Sound-wide program because of their well-established ambient monitoring program. Natural Resources is the most likely agency to lead the pilot study because of recent caged mussel monitoring and interest in monitoring indigenous mussel populations.

The Puget Sound Mussel Watch program would build on the current monitoring by agencies that are part of PSAMP monitoring and integrate annual monitoring by the NOAA Status and Trends Mussel Watch Monitoring Program. The primary difference between the NOAA program and the one proposed here is the combined use of natural bivalve populations and caged bivalves. It is anticipated that, like the State of California program, the Puget Sound Mussel Watch program will emphasize the use of existing mussel populations. Caged bivalves will be used at the most important areas where transplant studies are most beneficial and in focused studies, as currently conducted by the Washington State Department of Fish and Wildlife on fish populations as part of PSAMP. The rationale behind this approach is to maintain a core group of stations that are monitored on a yearly basis and more intense sampling obtain the necessary information in more problematic areas on a more limited temporal basis. A similar approach is being used by the Department of Ecology and PSAMP in sampling for eutrophication and associated oceanographic processes.

**Using an Exposure-Dose-Response Triad for Puget Sound Monitoring**

The exposure-dose-response (EDR) paradigm will be a key element of the Puget Sound Mussel Watch program. This triad was conceived to support Ecological Risk Assessments (ERAs) by including integrated, direct measurements of exposure and effects. Although the triad was developed and refined using mussels (Figure 4), it is applicable to and most informative if applied at several levels of ecological organization. The EDR triad is based on weight-of-evidence and is recommended for assessments that require site-specific data to more fully characterize exposure and ecological effects with reduced uncertainty. Characterizing exposure is probably the single most important element in EPA's risk assessment paradigm and sediment evaluations in the Superfund process. Effects occur as a result of chemical exposure and associated biological uptake. If exposure is not properly characterized, the effects measurements may not be meaningful or reproducible, and the conclusions based on those characterizations may be misleading. This may be the single largest uncertainty associated with laboratory toxicity tests, the sediment quality triad, the AET, and current Dredged Material Management Program (DMMP) approaches; exposure is assumed from the results of effects measurements.

The key difference between the EDR triad, other triads, or less-integrated approaches is the requirement to quantify the dose through tissue chemistry and biomarkers (Figure 5). A distinction is made between

**exposure** and **dose** because the exposure concentration (i.e., the concentration in environmental media such as water and/or sediment) is often different from the dose (i.e., the concentration of a contaminant at the receptor site). Dose is estimated by measuring chemicals in tissues while exposure is estimated by measuring chemicals in environmental media (water and/or sediment). Water and sediment, even if highly contaminated, only constitute potential exposure or external exposure, because bioavailability is controlled by many physical and chemical factors. It is important to measure the **dose** because it has been demonstrated that biological responses are related to the **dose** or **internal exposure** and not necessarily the **external exposure** concentration. In the EDR approach, response is estimated with effects measurements from bioassays and community structure analyses, both of which are conducted in the lab and field.

Another difference is the use of manipulative field bioassays and community studies to assess response. Tissue chemistry and biomarkers can be used to estimate dose while bioassays, fish health, and community structure can be used to estimate biological response associated with that dose. Together, the direct measures of water, sediment, and tissue chemistry from field-deployed organisms can provide a more complete characterization of exposure than traditional approaches using bioaccumulation measurements from laboratory bioassays.

The EDR triad incorporates components of the laboratory and field assessments identified in the original sediment quality triad, and extends the exposure-uptake-effects triad. Others suggest that integrated assessments should include at least two of the following basic elements: sediment toxicity tests, sediment chemical analyses, bioaccumulation, pathology, and community structure. However, the integration of any two elements may not ensure direct assessments of exposure and effects. Chemical measurements of environmental media only represent external exposure, and results from laboratory bioassays and analysis of community structure only infer that exposure to internal receptors has occurred. To reduce uncertainty, the most direct method of assessing internal exposure at the receptor is measuring the dose, or tissue burdens. To be consistent with the generic ecological risk assessment framework, the process should always include a direct characterization of exposure and a direct characterization of effects. Rather than allowing the option of selecting any two elements that may not include exposure and response, the EDR triad specifies the use of all three elements.

**Bioaccumulation and Biomarkers: Links between Laboratory and Field Studies**
Bioaccumulation and biomarkers can be used to establish links between laboratory and field monitoring programs currently used in Puget Sound. Tissue chemistry data can be used to establish a link between exposure and effects as well as other commonly used effects-assessment endpoints (Figure 6). Tissue chemistry and effects data are most meaningful when they are collected from the same organism at the same time. This has been successfully accomplished by NMFS and Fish and Wildlife by combining tissue chemistry, biomarkers, and effects endpoints in their Puget Sound monitoring. This integration has also been proposed as part of a revised bivalve test for bioaccumulation to include effects endpoints like growth.

Tissue chemistry and biochemistry can be considered the hub or common currency that can help bring these various programs together (Figure 6). The first link is between tissue chemistry/biochemistry and water/sediment chemistry, which has traditionally been a major gap in field monitoring studies within Puget Sound. For bivalves, both tissue chemistry and biochemistry can provide the link between results obtained by monitoring natural bivalve populations and caged bivalve bioassays. For fish, tissue chemistry can provide the link between fish health and fish biochemistry, such as currently being conducted by NMFS and Fish and Wildlife. Finally, tissue chemistry and biochemistry can be used to establish links between benthic communities and laboratory studies based on single species bioassays. Therefore, not only can tissue chemistry and biochemistry be used to establish links between field monitoring studies but also to establish links between field monitoring and laboratory monitoring studies; i.e., the **universal link**. Just as elements of the EDR triad are used to establish links within field monitoring and with laboratory monitoring for ecological assessments, the same elements within Mussel Watch monitoring would be used to establish links with the major elements of PSAMP; i.e., toxic contamination, human health, biological resources, pathogens and nutrients, and physical environment (Figure 7). Tissue chemistry can also be used to predict effects. Body burdens associated with adverse effects in previous laboratory and field studies can be used to establish effects thresholds. Biomonitoring that includes the measurement of tissue chemistry and biomarkers in fish and mussels can be compared with these predicted thresholds and used to establish Puget Sound-specific thresholds, as with the AET approach (Figure 8).

Recently, we conducted a series of cooperative studies with Environment Canada demonstrating the utility of caged mussel monitoring and bivalve biomarkers. This work suggests that specific bivalve biomarkers, such as the vitellin assay, can be used as an indicator of reproductive effects and endocrine disruption and to establish links with fish studies such as those currently being conducted by NMFS and Fish and Wildlife. Other biomarkers, such as the comet assay, have been used to establish genetic damage and those could also be correlated with the fish studies. Biomarkers can also be used as an indicator of bacteriological stress and possible human health. Currently the Orange County Sanitation District is planning caged bivalve studies as a forensic tool to establish the source of coliform bacteria that have caused the closure of the Beaches at Huntington Beach, California in 1999 and 2000. The City of Santa Barbara has previously used a similar approach. Although Washington State Department of Health has used caged bivalves for monitoring biotoxins, they have not used this approach for traditional bacteriological monitoring. The rationale for this approach is that the bivalves concentrate and integrate bacteria in much the same way that they concentrate and integrate chemicals. The concept is not exactly the same because the bivalves are able to ingest and digest some of these bacteria, but the overall concentration of bacteria in the bivalve is still concentrated by a factor of 10 to 100 times over the concentrations found in water. This approach also has the same advantage of integrating exposure to bacteria in the water column and provides more information than analyzing thousands of water samples. Another application to human health is the estimation of bioconcentration factors (BCF) from water, bioaccumulation factors (BAF) from water and food, and biota-sediment-accumulation factors from sediment.

**Implementation, Cost Sharing, and Services Sharing**

**DNR-Aquatic Lands Division** could be the lead agency on the pilot Puget Sound Mussel Watch Monitoring Program. DNR will fund the collection of mussels (and/or other bivalves) from approximately 20 stations throughout the sound, strategic deployment and retrieval of caged mussels at approximately 10 stations at selected sites where natural mussel populations are not available and/or where focused studies are needed to help characterize and understand exposure and effects in fish or other species.

**DNR-Wastewater Treatment Division** has used both natural populations and caged mussels to monitor and assess contaminants and fecal coliform bacteria and is currently considering using natural populations of freshwater clams and caged clams to monitor selected sites within Lake Washington. King County DNR will coordinate their efforts with respect to fecal coliform bacteria monitoring with Health and optimize the potential for a sentinel-monitoring grid by placing caged mussels on selected oceanographic monitoring instrumentation as a platform of opportunity. King County DNR has used both natural populations and caged marine mussels to monitor selected CSOs and is currently preparing to implement the use of caged mussels on oceanographic moorings to collect data that will be used as part of the ecological risk assessment to select a site for the new north end treatment plant. King County DNR will continue to monitor sediment, marine, and freshwater and provide guidance on the selection of sites for the Mussel Watch monitoring to better integrate data collection with other programs such as monitoring for phytoplankton, nutrients, dissolved oxygen, and subsequent water column modeling as well as participating in focus studies at selected locations by using their instrumentation (e.g, CTDs, phytoplankton sampling, and sediment traps). King County will provide funding for Mussel Watch monitoring at sites specific to their CSOs or freshwater Mussel Watch monitoring in Lake Washington.

**Health** will continue to monitor fecal coliforms and biotoxins at approximately 30 stations throughout the sound on a regular basis but at least once per year will provide additional samples for chemical analysis and mussel growth metrics to estimate mussel health. Health will also provide in-kind services for analyzing mussel tissues from the additional 20 to 30 stations where DNR collections are made.

**Ecology** will continue to monitor sediment, marine and freshwater and provide guidance on the selection of sites for the Mussel Watch monitoring to better integrate data collection with other programs such as monitoring for phytoplankton, nutrients, DO and subsequent water column modeling as well as participating in focus studies at selected locations by using their instrumentation (e.g, CTDs, phytoplankton sampling, and sediment traps). Ecology will also work with NPDES permitees to contribute to funding

Mussel Watch sampling as part of their contribution to characterizing exposure and effects at their locations as well as establishing exposure and effects over space and time. Since oil spill monitoring and the establishment of baseline conditions for oil spills is part of the Ecology responsibility, Ecology will fund Mussel Watch monitoring specific to their needs at selected locations within the Sound and if they determine it would be helpful to establish additional sites outside the Sound such as on the Washington coast. As with the California Mussel Watch monitoring and regional monitoring in San Francisco Bay, Ecology may also decide to monitor selected freshwater sites (e.g., Spokane River, cranberry bogs, point sources) where additional information is required.

**Fish and Wildlife** has provided services in support of caged mussel monitoring at Cherry Point and other Puget Sound locations over the past three years and will continue to provide that support. Since oil spill monitoring and the establishment of baseline conditions for oil spills is part of the Ecology responsibility, Ecology will fund Mussel Watch monitoring specific to their needs at selected locations within the Sound and if they determine it would be helpful to establish additional sites outside the Sound such as on the Washington coast. Fish and Wildlife will also work closely with DNR in establishing Mussel Watch stations for specific problems such as the decline of herring stocks at sites like Cherry Point and to compare exposure and effects at other Puget Sound locations.

**US EPA** (US Environmental Protection Agency) will provide guidance on monitoring at Superfund sites and dredge disposal sites as well as continued advice on Mussel Watch monitoring for specific applications, such as monitoring the integrity of sediment caps, groundwater seepage, and integration with other *in situ* bioassays. The US EPA will provide funding for specific focus projects unique to EPA requirements.

**NMFS** will continue to monitor sediment contamination and fish health by measuring sediment chemistry, fish tissue chemistry lesions and biomarkers. NMFS and Fish and Wildlife will work closely with other agencies to integrate synoptic Mussel Watch monitoring coincident with a strategic number of fish monitoring stations. NMFS will also work with the Mussel Watch monitoring program to develop a suite of mussel health indices (e.g., condition index, growth, reproduction) and biomarkers (e.g., lysosomal latency, comet assay, p450 RGS) to establish links between fish monitoring results and Mussel Watch monitoring results. NMFS will also provide in-kind services by using the specific bivalve biomarkers they have developed (e.g., lysosomal latency) on mussels provided by Mussel Watch monitoring.

**NOAA** will continue to monitor their 14 Mussel Watch stations within Puget Sound and will work with Puget Sound Mussel Watch to establish additional sites within the sound and perhaps on the Washington Coast. NOAA also has some specific needs with respect to monitoring oil spills, quantifying exposure and effects for damage assessment claims, and protecting their sanctuaries on the Olympic Coast and Padilla Bay. The possibility of establishing an artificial mussel colony at Padilla Bay has been discussed previously, and NOAA expressed interest in providing support to measure tissue chemistry at those sanctuary locations. Padilla Bay volunteers could also be used to help establish the artificial colony as well as collecting and processing the mussel tissues for health measurements and chemical analysis. PSAMP should also consider the possibility that NOAA may not continue their Mussel Watch monitoring at the current level or at all.

**MRCs** (Marine Resource Committees) have been approached by Alan Mearns of NOAA to establish a Mussel Watch monitoring program in the Georgia Straits. If established, this Mussel Watch monitoring could be used to supplement the proposed Puget Sound Mussel Watch monitoring program.

**GBI** (Georgia Basin Initiative) would be well suited to a Puget Sound Mussel Watch monitoring program. The Georgia Basin Initiative has attempted to establish trans-boundary monitoring between the US and Canada, but previous attempts have not progressed very rapidly. The simplicity of Mussel Watch monitoring would facilitate cooperative studies with GBI.

**Shellfish Growers** not only have a stake in protecting their investment but have previously shown an interest in cooperating and assisting agencies in collecting samples from their farms. It is anticipated that the shellfish growers would support this program and perhaps even provide bivalves for transplant studies at low cost to the program.

**USGS** would have the additional benefit of mussel watch monitoring to supplement their current water quality monitoring in Puget Sound and to provide comparisons with mussel watch monitoring currently being conducted in other parts of the country.

## Summary and Conclusions

We need to change the way we think about current assessment and management strategies with equal emphasis being given to better integration of exposure and effects monitoring using a variety of species. This is best achieved by synoptic measurements of exposure and effects endpoints in the same organism rather than using different tests and different species. The new emphasis by US EPA and the DMMP agencies on better characterizing and understanding processes associated with bioaccumulative chemicals of concern in the environment reflect a growing regulatory understanding that these types of chemicals are more persistent, and the potential effects are more significant. It also underscores the need for environmentally realistic monitoring, more sensitive monitoring endpoints, and more emphasis on using bioaccumulation and biochemical monitoring to confirm that exposure has occurred. More sublethal endpoint monitoring, like growth and reproduction, are needed to assess potential environmental effects. A weight-of-evidence approach must be maintained in a monitoring strategy that includes elements of water column, sediment, and biota monitoring.

Finally, it is appropriate for PSAMP to reverse the approach being used in most water column and sediment testing that emphasizes the use of water and sediment quality guidelines to determine which laboratory tests should be conducted in a tiered approach that culminates in field validation. The PSAMP approach should begin with field monitoring to establish where effects have occurred. This should be followed by laboratory validation. This approach could also include more focused studies in specific areas as currently employed by PSAMP to help determine the status and trends of contamination, identify hot spots of contamination, identify potential multiple stressors, and determine the extent of associated effects. *In situ* bioassays, such as those employed by the DNR in 1998-2000 that combine the use of caged bivalves to quantify exposure and herring egg cassettes to quantify effects, could also be utilized. Recently, the American Society for Testing and Materials (ASTM) has adopted the caged bivalve protocols we developed over the past 25 years. The PSAMP is one of the best monitoring programs in the country, but it could be better with increased integration and additional monitoring tools. Integrated fish monitoring that includes tissue chemistry, biomarkers, and effects endpoints has been refined more in Puget Sound than anywhere else in the country. However, integrated Mussel Watch monitoring has other advantages that could enhance the current PSAMP strategy.